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Memo

Date: *September 14, 2105*

To: *RSC, I. Pinayev, D. Phillips, J. Tuozzolo, and A. Drees*

From: *D. Beavis* DB

Subject: *Radiation Issues Related to the CeCPoP Low Power Beam Dump*

The CeCPoP Project will use a steel beam dump that was constructed for ERL but never used or evaluated. This report will examine radiological issues related to the low power beam dump for electrons with energies of 2 MeV and 22 MeV for CeCPoP at RHIC intersection region 2. The issues addressed are:

- Beam dump heating
- Ozone concentration in the air
- Air activation
- Soil activation
- Water activation (Not addressed as there is no water in the beam dump)
- Residual activity

Description of the Low Power Dump

The beam dump is a cylinder of 1018 steel with a beam port. Figure 1 displays the beam dump with the 304 stainless steel beam pipe and window. The standoffs for the dump electrically isolate it from the stand. The ceramic spool piece electrically isolates the beam pipe in the beam dump from the rest of the beam pipe. The window at the end of the pipe is tilted at a 45° angle.

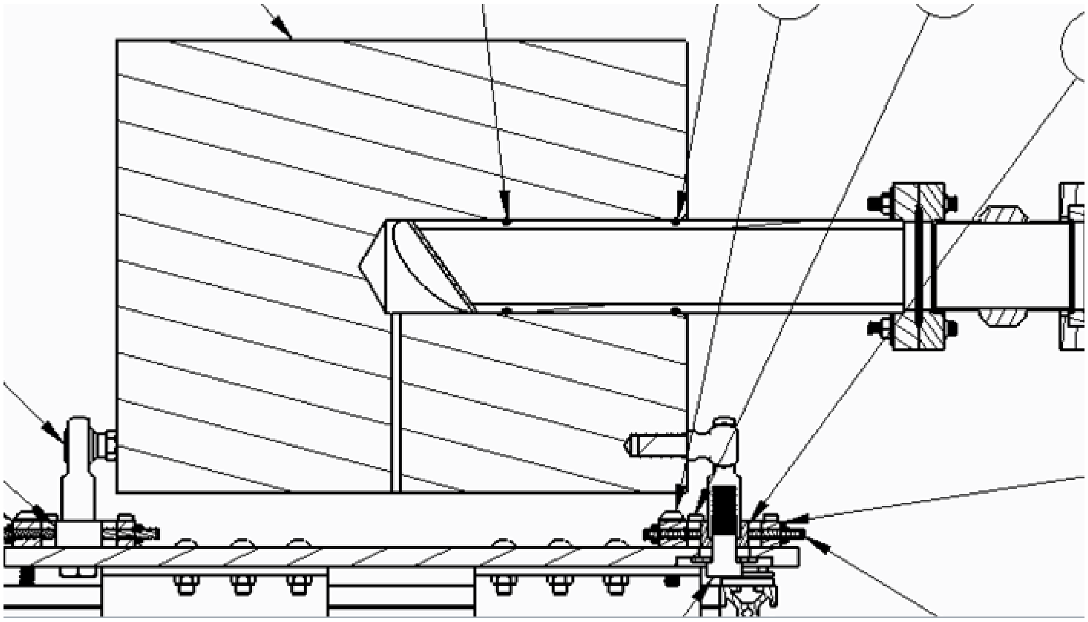

Figure 1: The low power beam dump. The main body is made of 1018 steel with a 3.2 cm radius hole to accommodate a stainless steel beam pipe. The beam pipe is isolated from the steel by two o-rings. The dump and beam pipe are electrically isolated from the stands and other equipment so that it can be used as a Faraday cup.

The beam dump was modeled in MCNPX. The model has the beam pipe from the isolation ceramic to the window. The tilted window was made perpendicular in the model to make the energy deposition calculations easier to tally. The window was made 41% thicker to account for the tilt. The dimensions of the steel and beam pipe are closely matched to the mechanical design. The electron beam was modeled as a parallel beam with a 3 mm sigma in x and y. The beam energies used were 2 MeV and 22 MeV, which are the expected nominal energies. Other beam parameters can be used as beam operations better define actual beam sizes and energies that will strike the beam dump.

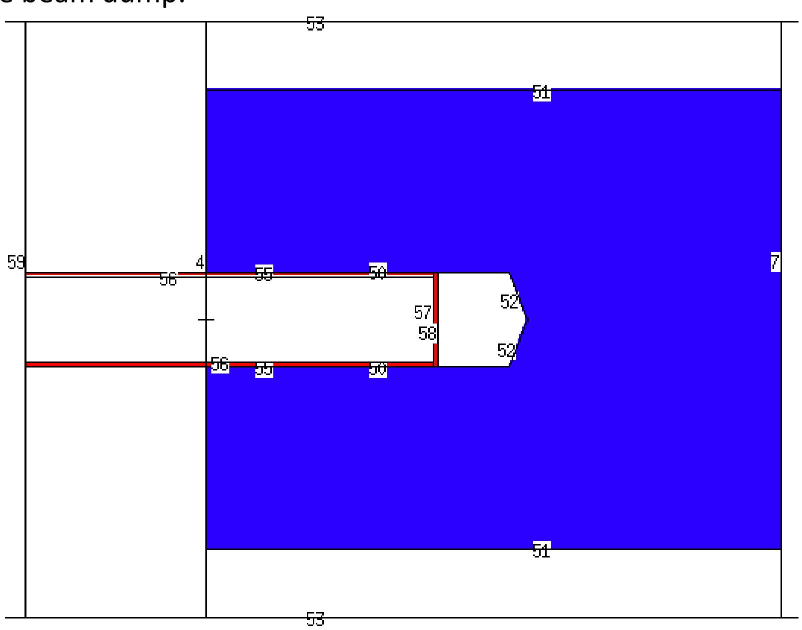

Figure 2: The MCNPX model of the beam dump

Beam Dump Heating

The project plans to operate 60 mW of 2 MeV electron beam into the low power beam dump. Initial calculations of energy deposition have been conducted for 1 W of 2 MeV or 1 W of 22 MeV beam. The energy deposition numbers can then be scaled to any desired beam power at those energies. The goal of the thermal analysis is to establish a safe beam power for the beam dump. The machine will be protected either by administrative procedures or the Machine Protection System (MPS).

The power density is calculated in W/cm^3 for the 1 Watt of beam. The results for the 2 MeV beam are shown in Figure 3 for the beam pipe window. The results for the beam pipe are shown in Figure 4. 0.902 Watts are deposited in the window and 0.078 Watts are deposited in the beam pipe. This accounts for 98% of the beam energy. The other 2% was not accounted for but is either photons escaping the beam pipe or back scattered electrons and photons going out the rear aperture of the beam pipe. The 98% is considered accurate enough for the thermal calculations. A center window temperature of 56^o C is obtained in preliminary analysis[1] for 1 W of 2 MeV electrons provides.

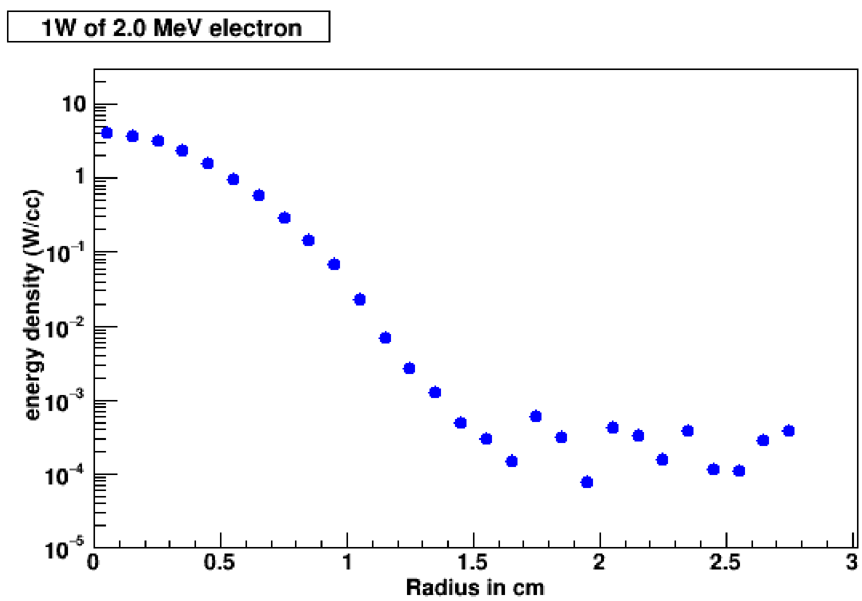

Figure 3: The power density in the beam pipe window for radial bins of 1 mm.

[1] C. Pai, "CeCPoP Low Power Beam Dump Thermal and Stress Analysis", Sept. 11, 2015, Powerpoint file

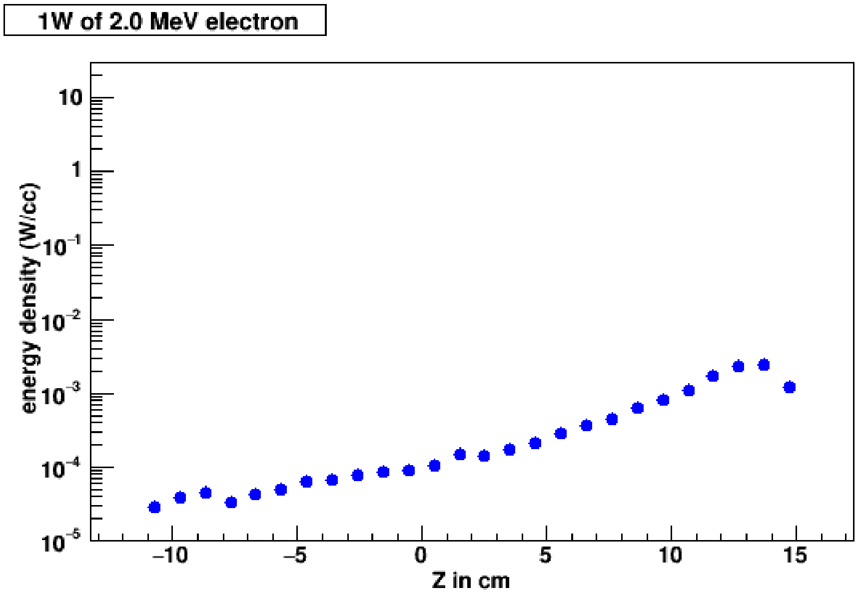

Figure 4: Power density as a function of the longitudinal coordinate along the beam pipe in 1 cm bins.

Energy deposition calculations were repeated for the 22 MeV beam. 22 MeV electron beam has sufficient energy to penetrate the window and deposit substantial energy into the beam dump steel. For this analysis the power density was tallied in four zones: the beam pipe, the beam pipe window, the core for the dump with radius[2] less than 3.2 cm, and the outer portion of the beam dump with radius greater than 3.2 cm. The power density for the four regions is:

region	Total beam power deposited
Beam pipe wall	0.0013
Beam pipe window	0.173
Dump core r<3.2 cm	0.582
Outer dump r>3.2 cm	0.237

99.3% of the beam power is accounted for in these four regions. Tabulated data has been provided to the engineering staff to conduct the thermal analysis.

Ozone Production

Ionization in the air around the low power beam dump can form ozone. There are published[3] methods for the estimation of ozone production in accelerator environments. The ozone molecules have a decomposition time of 0.83 hours in the absence of ventilation. It will be

[2] The hole in the beam dump has a radius of 3.2 cm. Thus this is the portion of the beam dump downstream of the beam pipe port.
[3] IAEA Technical Report no 188, 1979. See chapter 2.10

assumed that the beam will be operated for many hours so that the ozone concentration reaches the saturation value. The saturation concentration is given as

C=p*DT/V,

where p is the ozone production rate, DT is the decomposition time, and V is the volume of air.

The production rate is estimated by calculating the ionization that occurs in the air surrounding the dump. There are approximately 7.4 ozone molecules formed for each 100 eV of ionization. The model of the dump was surrounded by air for a radius of 10 meters and extending from 5 meters before the dump to 10 meters after the dump. The total energy deposited[4] in the air was calculated to be 5300 eV/s per 22 MeV electron into the beam dump. This leads to 226 ozone molecules per second per electron. The resulting concentration is $1.6*10^{-5}$ *(0.1 ppm). The 0.1 ppm is the TVL for ozone. The calculation was repeated for 2 MeV and found to be $1.2*10^{-4}$*(0.1ppm). This is a factor of ten higher than for 22 MeV. The ozone production occurs entirely in the backward direction. The results are well enough below the allowed TVL for ozone.

Soil Activation

High energy neutrons created in the beam dump create activation products that can be leached to the ground water. The concrete floor and roof are credible soil caps to prevent rainwater intrusion and the leaching of tritium to the groundwater if tritium was created by beam losses in the dump. It is worthwhile to obtain a simple estimate of the tritium even if credit is given to the concrete floor and roof as walls. The electron beam energy is sufficiently low that very few high energy neutrons are created. Typically, C-AD uses the neutrons with energy greater than 20 MeV to estimate the tritium production. The neutron spectrum drops rapidly as discussed in footnote 3. From the MCNPX results for 22 MeV electrons there are $1.2*10^{-12}$ neutrons/cm^2 per electron at two meters with an energy between 6 and 8 MeV. A rough extension to 20 MeV using a power law[5] in energy provides a order of magnitude estimate of 10^{-13} n/cm^2 per electron at 20 MeV. It would require 200,000 W-hours of beam into the dump at 22 MeV to approach[6] the BNL action limit. There is no soil activation concern[7] for the low power dump.

Air Activation

A simple and conservative estimate was conducted for the potential air activation due to beam into the LP beam dump. The 2 MeV beam is too low in energy to cause air activation. The 22 MeV beam can create air activation products from the bremsstrahlung radiation escaping the beam dump. For 22 MeV the only radionuclides of interest are ^{11}C, ^{13}N, and ^{15}O which are

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[4] The total energy rather than the ionization energy was used to be conservative.

[5] A power of -2.7 was used for immediate mass materials for extending the low energy neutron spectra.

[6] This estimate assumes the soil is at a distance of 2 meters and does not account for the shielding by the concrete floor. A more realistic calculation for 22 MeV would be expected to be orders of magnitude lower than the simple estimate conducted here, since the beam energy is so low.

[7] The BNL action limit would be approximately a total of $2*10^7$ tritium atoms per cc of soil

created by (g,n) reactions. Details related to these reactions are given in Table XXXb of Footnote 3. Assuming 1W of beam and an average path length of 10 meters the saturated activities and concentrations are:

Air activity from Low Power beam dump at 1W of 22 MeV

nuclide	Saturation activity[8] micro-Ci	Saturation concentration[9] pCi/cm^3	Half-life Min.
^{11}C	0.005	$8*10^{-6}$	20.34
^{13}N	140	0.22	9.96
^{15}O	15	0.024	2.05
^{39}Cl	0.4	$6*10^{-4}$	55.5

These numbers are expected to be conservative. The self-shielding of the beam dump has not been taken into account and this method is more appropriate for higher energies. Typical Derived Air Concentrations (DACs) are of the order of a few pCi/cm^3. It is clear from the DAC values given in 10CFR835, DOE guide G 441.1-1C, and the BNL Radiological Control Manual that these nuclides produced in the air will not be an issue for external dose or inhalation exposure. The concentrations can be used in a transport model to estimate the potential exposure to a person off-site.

Residual Activity

The residual activity of the beam dump should be small due to the combination of low power and low beam energy. We can estimate the potential activity for 1 Watt of 22 MeV beam using Table XIXa of footnote 3. Using 25 MeV in the table the saturation activity of ^{53}Fe is 19 MBq. The saturation activity of ^{56}Mn is 0.89 MBq. Immediately after shutdown the dose rate at a foot would be 3.6 mrads/hr and would quickly decay since it is dominated by the ^{53}Fe, which has a half-life of 8.51 min. After a few hours the dose rate would be dominated by the ^{56}Mn and dose rate would be a few hundred micro-rad at a foot. The Radiological Control Technicians (RCTs) can conduct surveys of the area to ensure there is no unexpected buildup of activity.

[8] The ^{11}C activity is so low since the 22 MeV is below the threshold for spallation production.
[9] A volume of $6.2*10^6$ cm^3 has been used representing a cylinder 5 meters in radius and 20 meters long.